

April 21, 1959

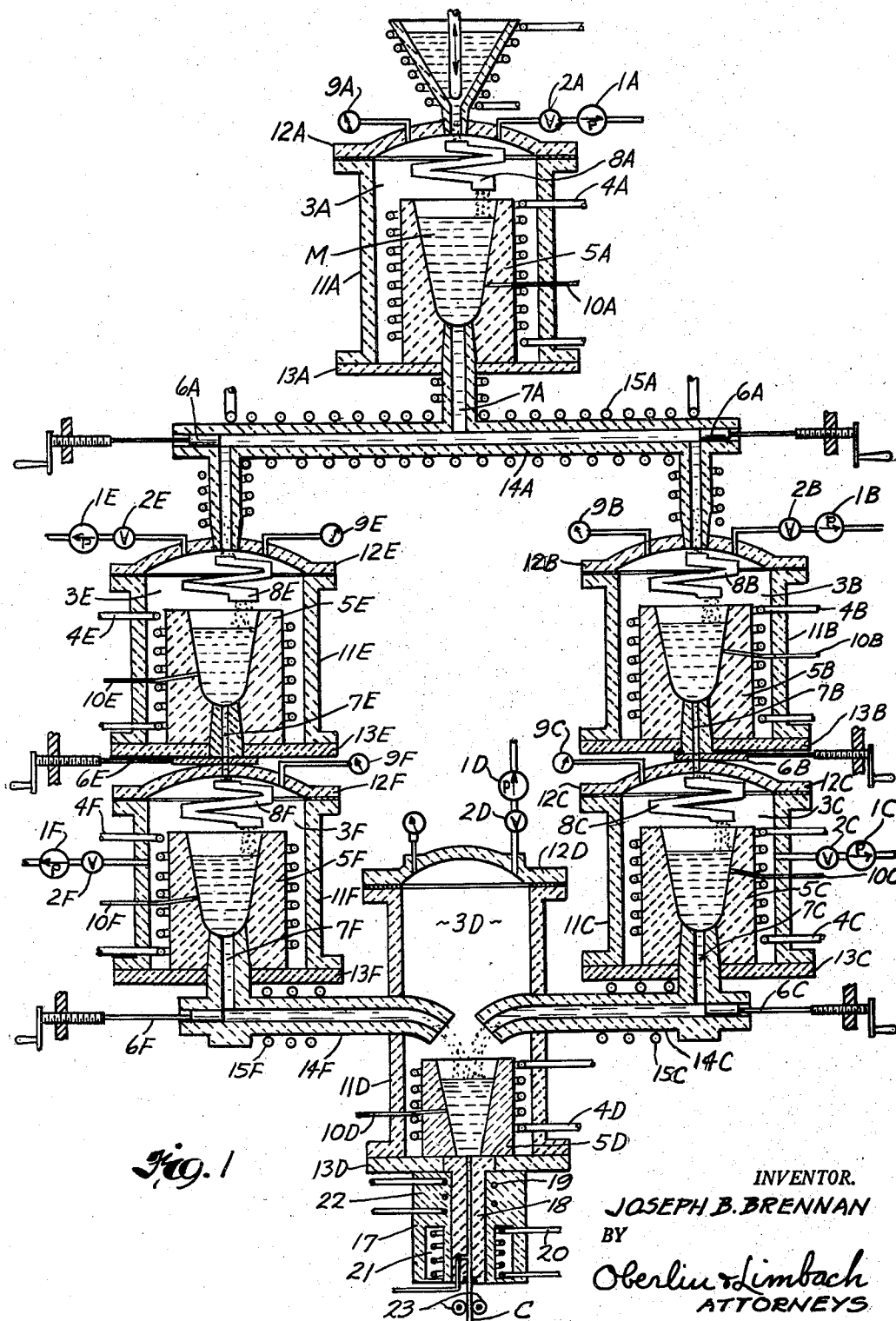
J. B. BRENNAN

2,882,570

CONTINUOUS VACUUM CASTING

Filed May 22, 1956

3 Sheets-Sheet 1



April 21, 1959

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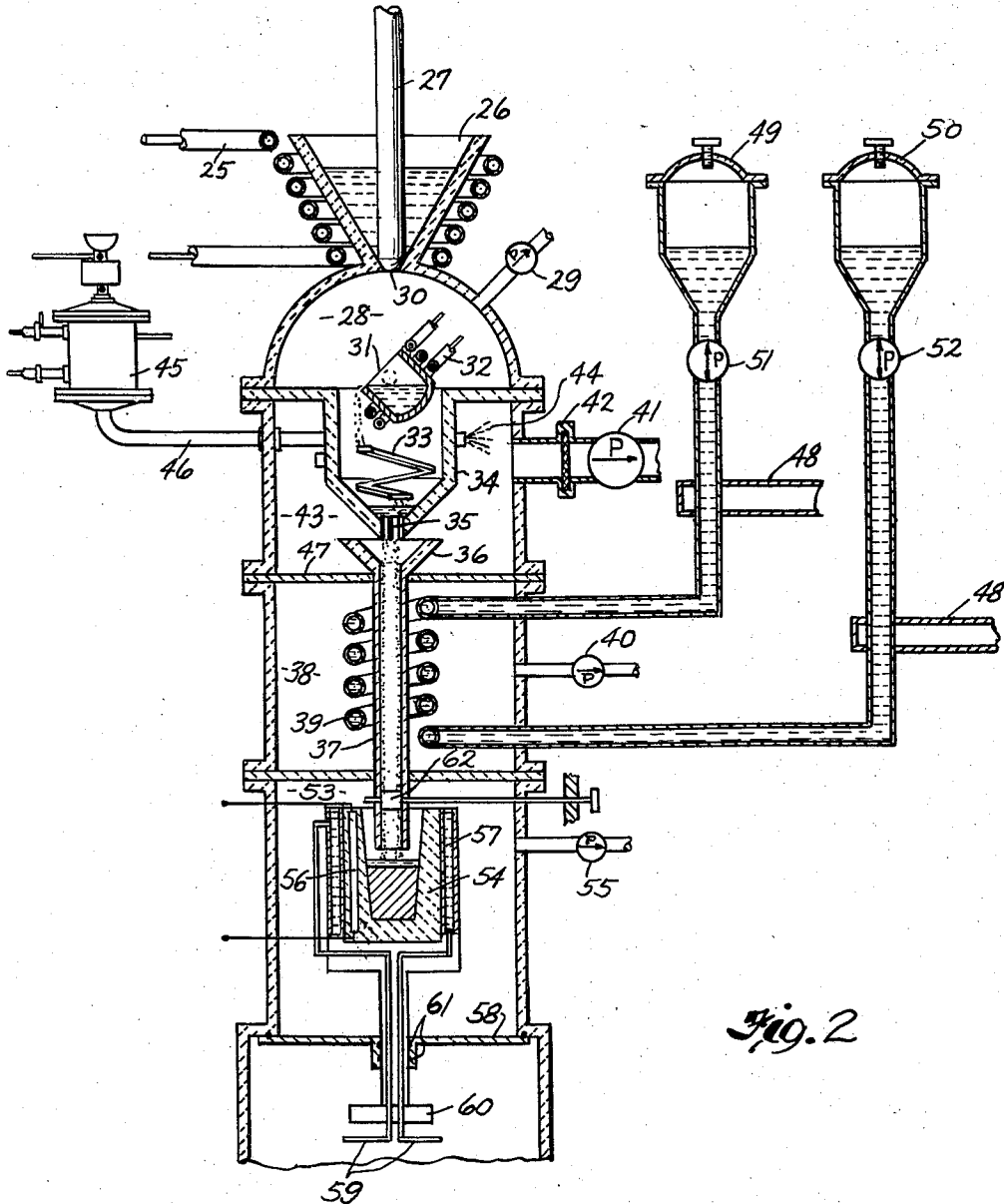


Fig. 2

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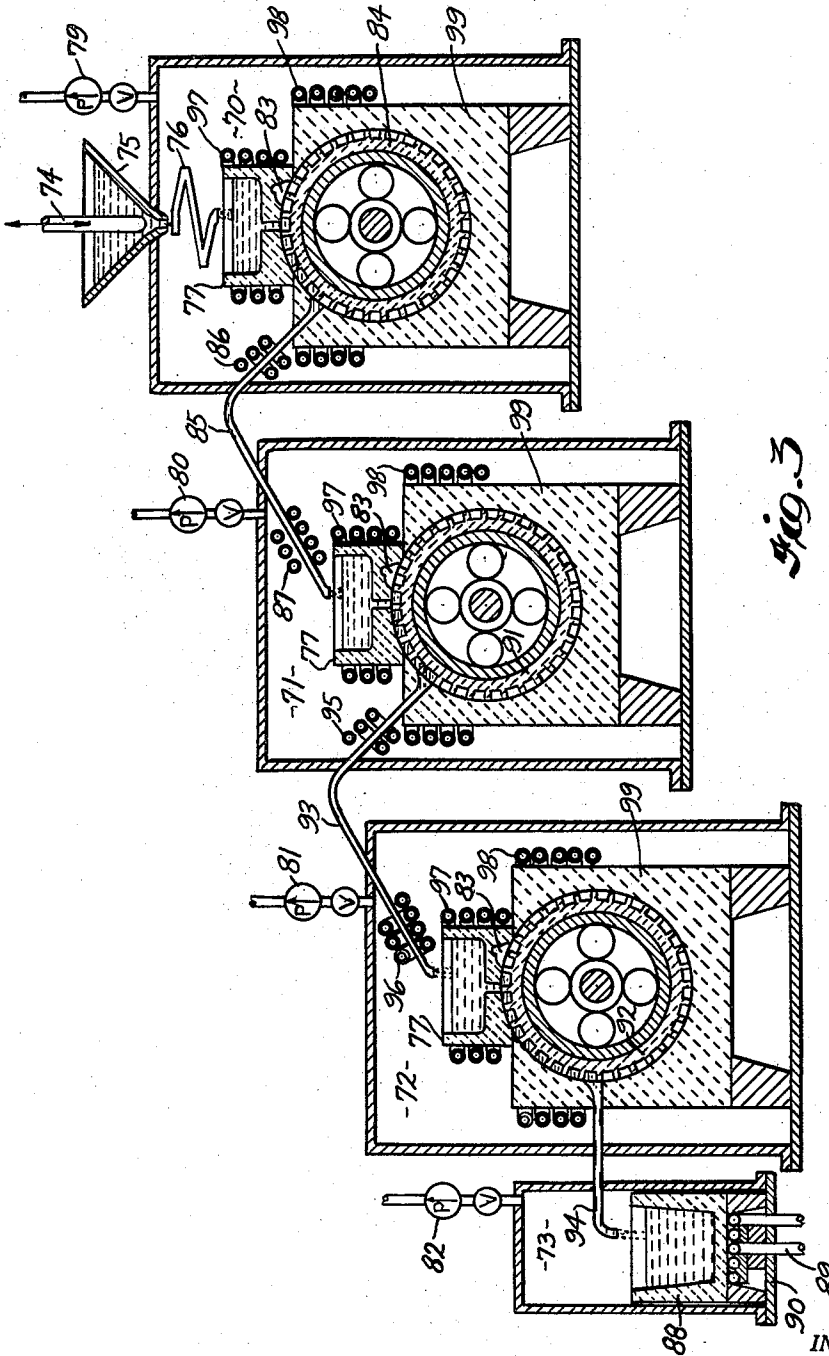
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CONTINUOUS VACUUM CASTING

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3 Sheets-Sheet 3



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2,882,570

CONTINUOUS VACUUM CASTING

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Application May 22, 1956, Serial No. 586,627

7 Claims. (Cl. 22—200)

This invention relates to casting and de-gassing of metals under high vacuum continuously.

Heretofore there has been no known process of continuously de-gassing large quantities of metal to make multiple tonnage castings therefrom under high vacuum.

According to this invention castings can be made as individual units in large bodies up to at least a couple of hundred tons and in large diameters up to at least 4 feet.

In order to make uniform large castings of this type it is necessary that the rate of casting be uniform and constant and the rate of de-gassing be constant and uniform and the de-gassing, when making the final casting, must be on the order of from 5 to 50 microns, for example, when casting an ordinary acid steel to attain the ultimate in density and uniformity such as is necessary when making castings from which large rotating bodies are to be fabricated subsequently.

Up to the present a single de-gassing of a stream of molten metal or of a spray of molten metal has been practiced as is described in my U.S. Patent No. 2,716,790, issued Sept. 6, 1955, and in my pending application Ser. No. 505,099, filed May 2, 1955, of which this application is a continuation in part.

This application relates to improvements over methods and apparatuses disclosed in my copending applications, Ser. No. 485,454, filed Feb. 1, 1955, Ser. No. 356,819, filed May 22, 1953, Ser. No. 406,809, filed Jan. 28, 1954.

According to this invention multiple sources of supply molten metal can be used to supply a multiple arrangement of independent de-gassing vacuum chambers with molten metal whereby molten metal is passed in a jet or spray through the upper part of each of the vacuum chambers and deposited molten in the lower portion of each of the succeeding vacuum chambers and passed therebelow through another nozzle or orifice to form a jet, or spray into preferably one or more vacuum chambers therebelow. Each of these vacuum chambers into which the metal is introduced has individual or at least several vacuum pumping mechanisms and vacuum control mechanisms so that different degrees of vacuum can be applied to the metal the further along or the further down it goes and as it advances through the various vacuum chambers. Several or all of these separately evacuated vacuum chambers are interconnected in series so that as each jet of metal goes into each vacuum chamber it is subjected to higher and higher vacuum the further along or down it goes, and then these vacuum chambers lead into the final casting chamber and the molten metal from these vacuum chambers is fed into a common casting chamber, either as each series one at a time, or several of the series concurrently, so that the same high degree vacuum can be maintained in the final large chamber that is maintained in the next to the last smaller vacuum chamber. While one may be only able to maintain constantly in the first vacuum chamber one milliliter of vacuum, in the last and final chamber it will be possible to maintain continuously, vacuums as low as

2

5 to 50 microns. In this way large quantities of metal can be de-gassed continuously, even several tons per minute can be de-gassed with multiple successive independent vacuum systems applied to the same metal stream as the stream is exposed successively.

It is also possible, according to this system of circulation, division, and variation in pressure through a series of vacuum chambers, to keep the ultimate casting conditions entirely constant so that the final casting is made in quiescence and without breaking of the jet or stream feeding the final cast.

When starting, each of the vacuum chambers which supply the final casting is brought to the desired vacuum prior to permitting any of the metal to enter the final casting chamber.

It is preferable to maintain a considerable difference in vacuum between the various vacuum chambers. A three or four stage system is generally suitable for bringing the gas content of molten steel down from, say 50 cc. per hundred grams, to 3 cc. per hundred grams.

It is generally preferred to feed molten metal into the principal supply chamber or trough for feeding the various uppermost, or first vacuum de-gassing chambers, however, it is possible to feed the molten metal chamber and the subsequent vacuum chambers thereafter, for example, as is illustrated in Fig. 1 of my pending application, Ser. No. 406,809.

The temperatures can also be varied as progress of molten metal through each vacuum stage is had by varying the electric input into the induction coils which are separately controllable.

At all stages for casting it is desirable to keep the molten metal at a temperature low enough to prevent evaporation and segregation of elements desired in the final stage finished casting and above the temperature at least at some stage prior to the final stage of evaporation—that is, above evaporating temperature of the unwanted elements in the final casting.

By this apparatus and method, continuous fractional distillation and separation of metals is effectually accomplished because the temperature and the degree of vacuum of each stage can be closely regulated. Moreover, the rate of flow and the rate of ingress and egress of the metal from, and out of each stage and vacuum chamber can be timed and controlled.

It is preferable that for greatest productivity, temperature, rate of flow, and rate of exposure to the vacuum for a given metal or its alloy be held constant at each stage and this can be done because of the preferred independent heating system and the novel multiple stage segregation of the continuous de-gassing and casting elements.

The rate of flow from each vacuum stage can be regulated by balancing orifice size of the outlet and the difference in vacuum at the next stage; also taking into consideration the metal head and the temperature.

A small stream of metal is preferably fed down from each crucible in each stage into the stage therebelow and may be regulated by a valve or orifice for a given metal and given vacuum difference provided the viscosity of metal at this stage is held constant by temperature control means; also delayed drip progress inside a nozzle well, spaced away from the fluid metal whether it be inside or outside by a die chamber, ceramic arrangement being such that an orifice is presented that will permit the controlled temperature and controlled pressure metal to feed at a constant rate.

There can be some ion leakage—that is, gas leakage, from an upper stage to a lower stage in this process and there is bound to be some included in the fluid metal mass, or streams, or sprays as the metal flows through the system and is evacuated. It is preferred that when,

and if the streams are fed from one vacuum chamber to another they be in small enough streams so that the vacuum therebelow into which they flow will break them up rather violently so as to permit a constant degree of de-gassing in the stage into which they flow. A preferable way of de-gassing is also to use particulate molten evaporated and sprayed metal in the higher stages of the vacuum system, which sprayed, evaporated metals have an affinity for the volatile impurities present in the metal being processed and de-gassed, thus by spraying and evaporating particulate molten metal showing preference for the volatile impurities present at a lower temperature than the value of metal being processed can be used advantageously and then collected in a trap in the exhaust system where it can either be used as a deposit or removed when condensed.

Thus by this system I am able to de-gas at a rapid rate in sealed, separate successive chambers having variable progressively higher vacuums and having successive heads in each variable vacuum chamber, ending in a constant vacuum chamber wherein there is no turbulence in the stream of metal fed therein due to the fact that all the volatile impurities which are immovable by vacuum, as well as with the assistance of particulate molten materials, vapors, or particles used in the process thereabove have been removed prior to entering the last stage and thus quiescent, dense castings can be deposited in the last stage at a rate only limited by the cooling.

It is preferred to completely solidify the casting in or below the last stage prior to removing it from the vacuum system.

Continuous vacuum castings can be made according to this invention and may be continuously removed from the system, preferably by fluid sealant in, or below the cooling zone or die.

Purification of metals can be had by this multiple stage de-gassing process by variation in temperature at each stage so that evaporable elements of the mixtures or alloys which it is desired to solidify, can be removed and collected through and in the exhaust systems.

The most readily evaporable elements are removed in the upper lower vacuum chambers and the higher evaporating elements in the lowermost and higher vacuum chambers.

Where induction coils are used in the vacuum system it is preferable to have them filled with a relatively high vapor fluid metal such as sodium or aluminum enclosed in a metal sheath or tube, or coil with a dielectric ceramic thereover. In this way it will not be necessary to use water inside the induction coils to keep them cool if higher than normal frequencies are used. The maintenance of a lesser degree of evacuation in the topmost vacuum chamber, or series of de-gassing chambers permits de-gassing in each stage with little turbulence and with controlled turbulence, and this prevents a good deal of the annoying and wasteful spattering generally encountered in de-gassing metals.

The number of stages to be used in de-gassing metals is relative to the degree of purification and de-gassing wanted and economically feasible.

According to present methods of de-gassing large bodies of metal, enormous time delays are encountered in order to do an effective job. Usually in the first stage of de-gassing large quantities of metal at best only about 50% of the contained volatile impurities can be removed.

Prior practice has been to freeze the metal after the first stage of de-gassing and re-melt it in order to attain further de-gassing, but according to this process it is not necessary to re-melt, and very little, if any heat is required except when initiating production to degas and get the metal to flow as desired through the entire system.

At certain stages of the process it may be desirable to superheat metal in order to remove an unwanted por-

tion thereof. Even in the final degassing stage it may be desirable to evaporate the remainder or to distill it to make metal deposits of collected particles thereof, or to make coatings therefrom. It may be desirable in some of the stages to resort to centrifuging or other means of breaking up the stream or body, or pool of metal in order to accelerate and make more uniform the processing thereof.

With apparatus and method of this invention, degassing of steel can be carried out at the rate of 5 lbs. to 5 tons or more per minute. With 4 stages of 1000 liters per second capacity, and 1 mm. Hg pressure first stage, and the last stage less than 100 microns pressure and the openings in between the various stages being approximately $\frac{3}{16}$ sq. in. it is possible to degas 5 pounds per minute of ordinary acid open hearth steel so that a quiescent casting can be had in the last stage even though the pressure be between 5 and 50 microns.

It is preferred to have metal flow control valves in between each successive vacuum chamber for flow control.

The quiescent jet, or stream, or spray casting under vacuum of less than 50 microns in the lowermost high vacuum chamber prevents mold splashing and rough surfaced castings resulting therefrom.

The continuity of the operation permits the maintenance of constant conditions of temperature, gas pressures, fluid density and rate of cooling aside from getting rid of volatile impurities. Uniformity in end product castings, be they large or small, is thus assured when sufficient separate stages are used and independently subjected to temperature and vacuum control.

It is generally true that there are several gas producing, or vaporizable contaminants in metal melt which it is desirable, and wanted to remove through vacuum purification and distillation. It is only by having a batch of metal sequentially subjected to various degrees of vacuum in jet spray form and various temperatures that this separation in vacuum can be effectively achieved with economy.

The volume of gas removal in the first stage of degassing is greatest, although the degree of vacuum maintained is lowest in the first stage and successively lower volumes of gas are removed at each stage even though the degree of vacuum is preferably higher at each successive stage.

In the final stage the least volume of gas is removed from the jet and pool and the degree of vacuum is highest. The final casting stage may have a means of rotating the ingot mold or the continuous casting mold in the vacuum casting chamber similar to that described in Ser. No. 406,809, filed Jan. 28, 1954.

Either continuous or individual ingot casting may be utilized in this process with the same mechanism by merely changing the outlet apparatus. The sealing of a continuous casting and the continuous removal thereof, or slab casting, or strip casting by the sealing of the member as it emerges by passing it through a metal bath of a lower melting point metal, or other normally solid sealant meltable material. It is preferred to use a sealant which will be fluid or plastic, and which will not break down at these temperatures. The sealant should be applied after the continuous casting leaves a cooling zone surrounding the continuous casting. Large ingot castings can be made by using a rotary feed-out device which can be maintained under high vacuum as it is indexed out, and as it has the mold or metal therein for cooling under vacuum described in my patent application Ser. No. 505,099, filed May 2, 1955.

Another surprisingly good result which arises from multiple stage degassed metal is that it can be cast in inert atmosphere to great advantage and even in ordinary atmosphere from a ladle filled under vacuum without excessive gas being absorbed into the casting; thus a

dense casting can be had from a ladle of metal degassed down to 1 cc. of gas per 100 grams although it had at least ten times this much contained gas prior to the multiple stage degassing and the final casting will not show any appreciable variation in density or lack of uniformity due to contained gases.

Where a variety of metals or variety of gas contents are to be handled for purification and degassing it is desirable to have the orifice in between each chamber interchangeable, and also to have a valving mechanism to regulate the flow of the metal through each orifice into the next succeeding vacuum chamber.

Multiple jet outlets can be used to advantage to increase the rate of degassing under certain conditions and the number of chambers required for a given job will be changed to best suit the job according to the quantity and type of impurities which it is desired to remove. For this reason it is preferable to have intermediate chambers between the principal first feed-in chamber and the last degassing chamber of similar and like interchangeable parts and with equal capacities so that the number of chambers desired can readily be interconnected, the vacuum itself pulling the various parts together and holding them in vacuum tight relationship with ordinary fluid cooled gaskets at the joints, or with refractory impervious members closely fitted by atmospheric pressure to effect a seal. The only regulation required is to change the orifice size leading from one metal pool to the next vacuum zone and keep the metal liquid and the vacuum at each stage constant and at least near non-splattering in the first stages and quiescent in the casting stage.

One or more sight glasses should be provided for each vacuum chamber unless transparent material is used for the vacuum chamber. The regulation of the apparatus can be had by regulating the temperature in each stage and the valve opening so that splattering does not occur excessively at any stage or in any vacuum chamber—that is, so that particles of metal are not violently thrown about in the vacuum chamber and deposited on walls thereof in such quantity that shutdowns may be required in 24 hours of operation.

Directional spraying of a relatively pure molten metal in a vacuum effects a mechanical separation of elements according to specific gravity of the elements. There is a great addition to the speed and degree of the high vacuum degassing of a chamber by spraying molten metal which has an affinity for the gases present in the vacuum chamber and re-collecting the gases and products of reaction with the sprayed metal in a trap on the way to the vacuum pumping system.

A relatively small size pumping system is required with each of the relatively small chambers in the constant flow multiple stage degassing system which permits the distance between the rotating elements which grab the ions and the distance of the ions to be removed to be shortened so that in the high or low vacuum stages greater efficiency is had by the mechanical system due to the nearness to, and ease of grabbing a given number of ions which it is desired to remove from the vacuum system and the metal being processed.

Heaters can be installed at every stage throughout the flow system so that at any time the system may be shut down or started up. It is preferable to have at least two paths or more for the flow of degassing metal to go from the initial source of what might be called raw molten metal to the final casting stage so that if there is any breakdown in the one line of flow from stage to stage, the flow can be kept up at a lesser constant rate and same degree of degassing casting. It will only slow down the rate of production but not affect appreciably the final product value because it can be supplied with heat for holding, and also for flow temperature control and to maintain the viscosity of the metals so that the same difference between vacuum stages can be had. This is

another reason for the valving in between stages of vacuum, that is, to permit repair, removal and replacement of any parts which need repair without shutting down the entire system.

It is contemplated to use either arc heating for the metal, or resistance heating, or frequency heating, or a combination. If frequency heating is used it is generally preferable in vacuum to insulate the turns of the frequency coils. In some instances it is desirable to use fluid metal inside the coils to lessen the danger of explosion which is encountered when water is used.

Alternatively, a refrigerated gas which is relatively inert can be used, such as for example, carbon dioxide, to cool the inductive coils.

The advantages which are present in using high frequency heating in vacuum degassing of metals is well known but they have been very difficult to achieve on a commercial scale because rather large quantities of heat are generally required to process large quantities of metal and to degas them fully and rapidly.

The multiple stage degassing system which permits high vacuum degassing at a high rate permits that only relatively small increments of heat are needed because of the smallness of the apparatus involved and smallness of pools of metal maintained in a vacuum chamber. There has been quite definite limitation on the number of tons of metal which could be processed in vacuum using induction heating. This is due to voltage limitation to avoid corona which necessarily limits the power input.

There has been also a limitation imposed due to the ultimate practical size available in high frequency heating equipment. According to this, my multiple stage degassing and casting system, these limitations are effectively overcome.

Referring to the drawings herewith and a part hereof:

Figure 1 is a cross section of a multiple stage, six-vacuum chamber degassing system with multiple separate degassing lines and chambers;

Figure 2 represents a multiple stage degassing system showing in cross section sprayed metal de-ionizer to assist the exhaust by independent diffusion and mechanical pumping systems; and

Figure 3 is a cross section of a pumping system whereby metals are centrifuged or otherwise pumped from one vacuum chamber to another operated at higher vacuum for degassing.

The following is a detailed description of Figure 1 and its parts and its method of operation according to this invention.

The reference numerals 1A to 1F inclusive represent six vacuum pumping systems which may include diffusion pumps as well as mechanical pumps. 2A to 2F represent valves and piping systems connecting the respective vacuum chambers 3A to 3F with the vacuum pumping systems 1A to 1F. 4A to 4F represent high frequency inductive heating coils surrounding the respective crucibles 5A to 5F, having molten metal M therein, and 6A, 6B, 6C, 6E, and 6F are valves reciprocable to regulate the respective outlet orifices 7A, 7B, 7C, 7E, and 7F in the respective crucibles 5A to 5F, except 5D.

In operation, the molten metal M is permitted to flow into the vacuum chamber 3A in droplet or spray form onto the trough 8A and from the trough into the pool of molten metal M in crucible 5A in the form of droplets as shown.

A vacuum gauge 9A is connected so as to indicate the degree of vacuum in the chamber 3A and the thermocouple 10A is used to indicate the temperature of the pool of molten metal M in said vacuum chamber 3A. This thermocouple 10A may be made so it can be removed and inserted at will. 4A represents a frequency coil which has a coolant circulated therethrough and a conductive element for the purpose of warming the pool M of molten metal and maintaining it at the proper temperature.

A casement 11A surrounding the vacuum chamber 3A is made of a gas impervious material and comprises the top 12A thereof and the bottom 13A thereof. The pool of molten metal M has an outlet 7A leading from the lower portion of the pool, or at least below the surface of the pool out through the crucible 5A which is situated within the vacuum chamber 3A, through a conduit 14A which extends at least two ways as shown and which permits the molten metal M to flow downward and outward so it can be regulated by the valves 6A. The conduit 14A and the crucible 5A are made of ceramic material. They can be made of aluminum oxide or mullite, lined with graphite, depending upon the metal which is being processed. A silicon oxide liner can be used also. It is preferable to have the liner fused and dense and in case graphite is used the conduit 14A has to be protected by a cover to prevent air erosion. The conduit 14A is preferably heated by high frequency coils 15A and the flow of metal through the conduit 14A is, as aforesaid, regulated by the valves 6A which may be independently adjusted and which are preferably made of ceramic material, or if made of metal, the metal is non-reactive with the molten metal being processed.

The outlets from the conduit 14A lead into the tops 12B and 12E of sequential vacuum chambers 3B and 3E so that a stream of molten metal which has left the pool in crucible 5A, flows in droplet form into the lower vacuum chamber 3B and 3E, over or through the trough 8B and 8E respectively.

Referring to the left hand line of flow in the drawing, there is also a vacuum gauge 9E connected to the vacuum chamber 3E and a separate vacuum system 1E and vacuum piping system and valve 2E connected to the vacuum chamber 3E, and the metal flows from the trough 8E into the pool of molten metal in crucible 5E.

A high frequency coil 4E surrounds the crucible 5E in the vacuum chamber 3E and a thermocouple 10E is operably associated with the pool of molten metal in the vacuum chamber 3E on the left which indicates the metal temperature in crucible 5E. A valve 6E is situated in the outlet 7E from the pool of molten metal in crucible 5E to admit the molten metal into the vacuum chamber 3F therebelow into the trough 8F to create another pool of molten metal which has been further degassed, as it passes into crucible 5F in atomized or droplet form. The valve 6F controls flow through conduit 14F into vacuum chamber 3D which surrounds the crucible 5D and which crucible and its contents are heated by the frequency coil 4D therearound. A coil 15F maintains the metal at the desired temperature. The conduit 9 leads into vacuum chamber 3D regulatable through the valve 6F and metal may be, as is illustrated, introduced in the form of particles but is preferably quiet and non-spattering and very directionally projected into the pool of molten metal in crucible 5D which is also heat controllable by the high frequency coil 4D and which crucible 5D is located in the lowermost vacuum chamber 3D. 5D is a crucible which may feed a continuous casting mold 17 which may have a metal die 18 and which is heat controllable by means of the frequency coil 19 surrounding it, or die 18 may be of graphite or other ceramic material. Also a thermocouple or heat indication means (not shown) should be applicable to die 18 so as to indicate the temperature of the metal in the final stage of casting.

A cooling coil 20 which may be of copper filled with a cooling fluid and in a dielectric bath 21 may be used also to control the temperature of the continuous casting C. The coil 19 can be in the nature of a surface heating coil which will only make the outside skin of the continuous casting C slippery. The cooling fluid 21 can be circulated to cool the continuous casting C through openings into the cooling chamber, not shown, and this cooling fluid can also be used to keep the temperature of

the frequency coil 20 from melting. The coil 20 should be operated at frequencies in excess of 400,000 cycles in order to have a pronounced skin effect, and is provisionally controllable by known means, not shown.

The coil 19 can be a frequency coil comprising a copper tube having coolant circulated therethrough which can also be used to cool the casting C as it descends and it can also be used to heat the casting C as it descends. In cases where it is to be used for heating the casting C as it descends, then it also should be a high frequency coil in the order of 400,000 cycles or more. Normally, however, only coolant fluid need be circulated through the frequency coil 19 which is embedded in a dielectric material 22. The rolls 23 are used for regulating the speed and withdrawing the casting C in case a continuous casting is made.

Looking at the right hand side of the drawing of Figure 1, 4B represents a heating coil, 9B a vacuum gauge, 1B a vacuum pumping system connected by 2B, the pipe and valve system, to the vacuum chamber 3B. 8B represents the down-feed trough, from which molten metal droplets descend into the pool of molten metal held by the crucible 5B. 6B represents the valving system which controls the flow of metal through 7B into the vacuum chamber 3C therebelow. Thus, again the molten metal flows in the form of a stream or droplets into the trough 8C and into the lower pool in crucible 5C. The crucible 5C is heated by the coil 4C in the chamber 3C. The vacuum chamber is designated by 3C and from this vacuum chamber on the right hand side of drawing Fig. 1 a conduit 14C leads into the final casting or vacuum chamber 3D. In other words, a number of conduits 14C and 14F may enter into the common lowermost vacuum chamber 3D and there the metal may be transformed into a single ingot casting or into a continuous casting C, as is illustrated in Figure 1 hereof.

Figure 2 of the drawings herewith illustrates another form of apparatus whereby a continuous flow of molten metal is subjected sequentially to various degrees of vacuum and relatively small pumping systems may be used to rapidly degas the metal exposed in spray, droplet, or jet form to the vacuum in the various chambers through which the flow of molten metal is sequentially exposed.

Reference number 25 of Figure 2 represents a frequency coil for heating the crucible 26 which contains a pool of molten metal which may be fed from a furnace such as an open hearth furnace, not shown, and which has an outlet valve 27 situated in the crucible 26 to regulate the flow of molten metal from the crucible into vacuum chamber 28 which is exhausted by the pumping system 29. Below the opening 30 in the crucible 26 the molten metal can flow into a tilting type crucible 31, heated by frequency coils 32, creating a pool of molten metal which is held at constant temperature and which can be fed in a broken-up stream onto and from the trough 33 situated in the vacuum chamber 28 and therebelow to create a pool in a crucible 34 having holes or orifices 35 in the lowermost portion so that the metal will divide as it goes into the ceramic funnel 36 therebelow and passes on down into the tubular portion 37 of said funnel. Said tubular portion 37 of the funnel is porous and is situated in the vacuum chamber 38 and is heated by inductive coil 39.

The vacuum chamber 38 is exhausted by the pump 40 to a higher degree of vacuum than that existing in the chamber 28.

In the chamber 28 of Figure 2 a sprayed quantity of metal as of, for example, sodium, potassium, or aluminum is used to increment the exhausting effects of the pump 41 connected into the pipe trap and filtering system 42 to the interior of the vacuum chamber 43.

A difference in degree of vacuum between the chamber 28 and 43 is maintained due to the exhausting pump 41 operating at a higher vacuum than the pump 29

thereabove, and also the spray 44 which is directed into the exhaust system 42 leading to the pump 41 which grabs many ions and assists in the evacuation of the chamber 43 by chemical reaction with the atomized particles of the spray 44.

45 of Figure 2 is a pressure supply means for supplying molten metal spray into the interior of the vacuum chamber 43 described in my pending application Serial No. 485,454, filed February 1, 1955, through the conduit 46, and it may encircle the crucible 34 as shown to assist in controlling the temperature of crucible 34 and its contents. The walls of the vacuum chamber 43 may be of any suitable impervious material as is well known. The partition 47 separates the chamber 43 from chamber 38 therebelow. Chamber 38 has a heating coil 39 situated therein for inductively heating the tube 37 through which a particulate molten stream passes downward. The frequency coil 39 may comprise an outer enclosure as of silica having a molten metal therein, which molten metal is in contact with the bus bars 48 so as to carry a frequency alternating current about the flow of molten metal downward through the tube 37. The current flowing through the molten metal will heat the stream of molten metal going through the tube 37. It is preferable to have the metal circulated through this system, of a relatively high vapor point so that in case the tubular system breaks down explosions will be avoided. 49 and 50 represent containers for the head of molten metal and the pumps 51 and 52 designate the circulation system used for maintaining these heads. The metal can first be circulated in one direction and then thereafter circulated in the other direction so as to maintain an electrical inductive system at 39 in the vacuum chamber 38. Such a system can effectively be used to heat molten metal in a crucible and lessens the danger of explosions compared to the use of water in these tubes for cooling.

In the lower vacuum chamber 53 a mold 54 is shown, having a casting made therein. The lower chamber 53 is exhausted by the pump 55 and a resistance heater 56 or a series of resistance heaters may be used to maintain the mold 54 at the proper temperature. Also, the mold 54 may be cooled by water cooling system 57 which may be situated as desired, on the sides or the bottom of the mold 54. The mold 54 may be of highly conductive material such as aluminum or copper and may be very thin if desired. It may also be a split mold. The mold 54 can be removed by moving the partition 58 downward.

Numerals 59 represent fluid cooling conduits for controlling temperature of the mold 54, and 60 represents a hydraulic lift, and the O-rings 61 seal in the sleeve of partition 58 and permit sliding of the mold 54 upward and downward so as to avoid splashing when the molten metal enters from the lowermost portion of the tube 37. A valve 62 is situated in the tube 37 to regulate the flow of molten metal from the lower end of the tube 37 into the mold 54.

Figure 3 shows a centrifugal transfer system between four vacuum chambers 70, 71, 72, and 73 for the purpose of degassing metals which can be handled by mechanical actuation. It is also possible to accomplish this somewhat horizontal transfer and spraying of the metal in the vacuum by electric induction effects.

A valve stopper 74 of ceramic is used to regulate the flow of molten metal from the crucible 75 into the first vacuum chamber 70 and onto the trough 76 therein so that it becomes a dispersion exposed to vacuum, especially as it drops from the trough 76 forming a broken up stream into the pool of molten metal in crucible 77 therebelow. The pool of molten metal is temperature controlled by induction coil 78 within the vacuum chamber 70. Each chamber 70 to 73 has connected thereto a vacuum system 79 to 82 respectively.

Below the pool of molten metal collected in the first vacuum chamber 70 is a rotary centrifuge described in

my copending application Serial No. 256,508, filed Nov. 15, 1951, now Patent No. 2,787,816, and which operates as described in this above mentioned application, whereby the vanes of the centrifuge are first evacuated through opening 83 which leads into the vacuum chamber 70 and hence permits and assists in the flow of molten metal into the peripheral spaces in the centrifuge 84.

After the molten metal has entered the peripheral spaces in the centrifuge 84 and moves counterclockwise, it is slung through the ceramic tube 85 out of the vacuum chamber 70 and into the vacuum chamber 71 adjacent thereto and somewhat below.

The tube 85 through which the metal is slung or pumped is temperature controlled by frequency coils 86 and 87 in chambers 70 and 71 respectively.

Thereafter, the processing of the metal is similar to that effected in chamber 70 except that it is at a higher degree of vacuum and it is slung out of the chamber 71 into the chamber 72 where a still greater degree of high vacuum is impressed on the metal therein and from chamber 72 it is slung into vacuum chamber 73 where the final casting may be made in the mold 88 after being cooled as a quiescent pool. The cooling coil 89 may be used to warm the mold 88, may be also used to circulate coolant therethrough for the purposes of solidifying the cast metal in the mold 88, preferably from the bottom upwards. The bottom 90 of the vacuum chamber 73 may be lowered for the purpose of removing the casting when it has been solidified under vacuum. Obviously mechanism for continuous casting and removal of cast metal accordingly may be effected. 91 and 92 are the centrifuges in chambers 71 and 72 respectively with conduits 93 and 94 leading the metal into chambers 72 and 73 respectively. Coils 95 and 96 are used for temperature control of the metal and frequency coils 97 and 98 are located around crucible 77 in each chamber 70, 71, and 72 and around each housing 99 around the respective centrifuges 84, 91, and 92.

The nozzles used in multiple stage continuous degassing are in reality regulating valves of a specific orifice size and shape which may be adjustable for different metals for admittance and flow control of molten metal between differing intensity vacuum chambers. They may be termed bleeder valves admitting gaseous metals of varying degree of gas content from stage to stage of vacuum exposure and jet spray and degassing, until preferably at the final stage all the removable gas is gone and the jet stream or flow is practically quiescent—i.e. without explosive tendency in high vacuum.

The dropping of the metal in Figure 2 occurs at high velocity of the droplets or lumps of metal for the purposes of casting through an evacuated chamber in tube 37 whereby the temperature of the metal may be controlled in dropping due to the surrounding frequency coil 39 and reactance with enclosing medium. The fluidity of the metal entering the mold 54 may be controlled.

In other words molten balls of metal are projected without appreciable contact with a reactive medium so as to alight in rest in a heat extractive mold 54 as a casting prior to solidification or as a part of a casting. That is, the metal retains its fluidity because of the velocity of casting even though it enters a cold mold. This velocity may be due to the acceleration of gravity due to extended height and distance of dropping, or may be accelerated by centrifuging or other mechanical means illustrated in Figure 3.

Other modes of applying the principle of the invention may be employed, change being made as regards the details described, provided the features stated in any of the following claims or the equivalent of such be employed.

I therefore, particularly point out and distinctly claim as my invention:

1. The method of de-gassing molten metal during the course of its flow from a supply crucible to a mold which

11

comprises successively exposing the metal to the de-gassing influence of progressively increased vacuum in successive vacuum chambers, and introducing the metal into a mold disposed in the chamber of highest vacuum.

2. The method of de-gassing molten metal which comprises successively exposing the metal to the de-gassing influence of progressively increased vacuum in successive chambers.

3. A method according to claim 2 wherein molten metal is passed from each such chamber to a succeeding chamber in divided form to increase the exposure of the metal and aid in the de-gassing thereof.

4. A method according to claim 2 wherein such molten metal is passed to a succeeding vacuum chamber by spraying such metal.

5. A multi-stage method of de-gassing and casting molten metal comprising the steps of successively exposing the molten metal to the de-gassing influence of progressively increased vacuum in successive interconnected vacuum chambers until the molten metal has reached a substantially quiescent state.

12

6. A method according to claim 5 wherein the de-gassed molten metal is introduced into a mold in the last of such interconnected vacuum chambers.

7. A method according to claim 5 wherein the de-gassed molten metal is introduced into a mold in the last of such interconnected vacuum chambers, and then continuously removing the molten metal from such mold.

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